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Use Impairment Associated with Drinking Water in the Great Lakes Basin. State of the Great Lakes Basin Ecosystem

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USE IMPAIRMENT ASSOCIATED WITH DRINKING WATER IN THE GREAT LAKES BASIN

(STATE OF THE GREAT LAKES BASIN ECOSYSTEM)

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SUMMARY

A study was undertaken to investigate the use-impairment associated with the presence of benzene, lead, aluminum, chloroform, trihalomethanes (THMs) and nitrates in the drinking water supplied to the communities of Toronto, Thunder Bay, Windsor, Milwaukee, Gary and Rochester.

The standards/guidelines used by Health and Welfare, Canada, the Ontario Ministry of the Environment, the United States Environmental Protection Agency, Related State Environmental Agencies, the World Health Organization and the European Economic Community for the selected chemicals were reviewed. The adverse effects of these chemicals and basis for adopting the recommended levels are reported. If more stringent goals/objectives have been recommended, these are mentioned.

Benzene is considered to be carcinogenic to humans. The concentration goal in drinking water is zero and standards have been set between 5 to 10 ug/L because of the limitations on analytic techniques and the cost of available technology. Benzene is generally present below the analytical detection limits in the data studied in this report. However, considering its carcinogenicity and recent wide use in gasoline, it should be monitored more frequently.

Lead is highly toxic to human beings and its concentration goal has been set at zero because it is classified as probable carcinogen. At present, lead is regulated at 50 ug/L; however, it has been proposed to lower the allowed concentration to 5 - 10 ug/L. In the future, it may be required that the water leaving the treatment plant be made non-aggressive to the copper and lead used in plumbing. In recent years, the lead concentrations in raw and treated waters have been generally below both regulated and proposed levels. However, Milwaukee, Gary, Rochester and Windsor have often exceeded these limits in the past. Windsor, in particular, had very high lead

concentrations in 1986 and 1987.

Aluminum is currently regulated at 50 ug/L due to aesthetic reasons. The USEPA and the WHO are preparing health criterion documents and in the future it may be regulated at a much lower level. Most of the time Windsor, Gary and Toronto and often Rochester and Thunder Bay exceed the limit of 50 ug/L. Generally, the treated water has a higher aluminum concentration than the raw water. All the communities studied exceeded 10 ug/L most of the time, even in their raw water. Under these conditions, appropriate technologies will have to be developed, in addition to substituting another coagulant for alum, to reduce aluminum in drinking water.

Chloroform is formed during water treatment process and is carcinogenic to animals and a probable carcinogen to humans. The WHO has established its guideline at 30 ug/L so as not to compromise the disinfection process. The USEPA is in the process of setting both a MCLG and MCL for chloroform in drinking water. The NRC, WHO and USEPA recommend that the chloroform concentrations should be reduced to as low as reasonably achievable, without compromising the disinfection process. Both Windsor and Thunder Bay drinking waters have exceeded WHO guidelines 40 % and 75 % of the time respectively, whereas other communities that have adopted some special methods to reduce chloroform formation, show lower concentrations. If chloroform standards are set at 15 ug/L due to health reasons and available technology, then Windsor and Thunder Bay will always exceed and Rochester and Gary will often exceed the limit.

Chloroform is only one of the four types of trihalomethanes formed during water treatment when free chlorine, used as a disinfectant, combines with natural precursors present in raw water. Three of these chemicals are probable human carcinogens and therefore THMs are regulated from 1 ug/L in several European countries to 350 ug/L in Canada. It is difficult to explain why Canadian

guidelines are out of step with the rest of the world. It is expected that the USEPA will soon set a new standard for THMs between 25 to 50 ug/L and will suggest technology to achieve it without abandoning the use of free chlorine. Windsor has shown the highest concentrations followed by Thunder Bay, Rochester, Toronto, Gary and Milwaukee. All of these communities satisfy the standard of 100 ug/L. However, if THM standards are lowered to 25 ug/L, Windsor and Thunder Bay will always exceed, Rochester will exceed 50 % of the time, Toronto and Gary will exceed less than 15 % of the time and Milwaukee will not exceed the limit.

Nitrates can cause methaemoglobinemia in infants if present above 10 mg/L as N. The raw and treated waters in all the communities studied had much lower nitrate levels.

There is not sufficient information available to predict long term trends for the chemicals investigated in this report. Considering the health significance of these chemicals, it is recommended that all communities should allocate sufficient resources to more frequent surveillance and monitoring.

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1.0 INTRODUCTION

The Great Lakes is the largest fresh water ecosystem in the world and serves more than 30 million people, both in Canada and the United States, for their drinking water needs. The quality of drinking water supplied to these consumers depends on the raw water quality in the lakes as well as on the treatment methods used in processing this water. Any impairment in raw water quality, directly or indirectly, can result in changing the processed water quality. Both in the United States and Canada, the drinking water quality is regulated through federal and/or provincial/state legislated standards.

The Great Lakes Water Quality Agreement (IJC,1989) between Canada and the United States addresses beneficial uses and their impairment within the context of the purpose of the parties "to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem". The beneficial use of the Great Lakes is specifically defined in terms of general and specific objectives, impairment and effect of hazardous substances. Recently, the Water Quality and Science Advisory Boards (WQB) of the International Joint Commission (IJC) have broadened the traditional state-of-the-lakes quality with an emphasis on ambient trends to state-of-the-ecosystem quality which includes human activities, effects and use impairment. The WQB has defined use-impairment as (WQB,1989):

- the effects observed within the living resources of the basin ecosystem that are not within normal bounds and that have proven to be the result of human activities;

- linkage between ecosystem effects and causes, particularly such stresses as chemical contaminants; and
- changes in the states of the lakes over time.

Each use-impairment requires characterization by a series of indicators which reflect the contaminant and other stresses on that use. The indicators selected for this characterization may include not only the traditional chemical parameters, but also non-chemical parameters such as taste, aesthetics and costs. No one indicator is sufficient but a combination of indicators can provide a reasonably complete picture. However, for certain necessary indicators, either data do not exist or the indicators have not been fully developed.

John F. McDonald and Peter C. Boyer of the International Joint Commission, Windsor, had asked J.K. Bewtra, P.Eng., Windsor, to undertake a study on the use-impairment associated with drinking water from the Great Lakes System. Five priority chemicals of concern and six strategically located urban communities in the Great Lakes System were selected for this purpose.

1.1 OBJECTIVES

The objectives set for this study were:

1. To determine the relevance of the drinking water restrictions described in the GLWQA i.e. "restrictions on drinking water consumption, or taste or odour" as applied in six selected major municipal areas in the Great Lakes basin. The areas of concern were Toronto, Ontario, Windsor, Ontario, Thunder Bay, Ontario, Gary, Indiana, Milwaukee, Wisconsin and Rochester, New York.
2. To apply the use-impairment guidelines developed and approved by the WQB to determine taste or odour problems or restrictions on drinking

water consumption, and provide comments and recommendations on their application or improvement.

3. To further consider the implications of any determined deterioration in drinking water quality on currently deployed water treatment technology and human health.

1.2 SCOPE OF WORK

The scope of the work specified in the Contract includes:

1. To assess the extent of use-impairment in terms of Annex 2, 1(c) ix of the GLWQA, for the selected locations;
2. To evaluate the suitability and status of Great Lakes water quality in terms of raw and finished drinking water for six urban areas in the basin; three in each country, using the relevant public health standards and criteria applicable for each jurisdiction;
3. To address the occurrence and the relevance of five priority chemicals in drinking water at the selected locations: benzene, lead, aluminum, chloroform and trihalomethane in terms of the health standards prevalent in other jurisdictions (e.g. Europe, WHO) and any implications for the health of the human population and the technology currently used to render raw water potable. Nitrate concentrations may also be considered, if appropriate, following the contractor's initial review of the literature.

1.3 TEAM

The following persons from the University of Windsor have participated in preparing this report:

J.K. Bewtra, Ph.D., P.Eng., Professor;

N.Biswas, Ph.D., P.Eng., Associate Professor;

Y.M. Xie, Visiting Research Scholar;

P. Henshaw, M.A.Sc., P.Eng., Graduate Student;

A. McCorquodale, Undergraduate Student.

2.0 INFORMATION AND DATA COLLECTION

A series of steps were initiated to collect necessary information and data required to meet the objectives of this study.

2.1 SOURCES

The sources screened for this study included:

- Making contacts directly or through the IJC to obtain raw and treated water quality data from the selected communities;
- Reviewing annual reports on water quality published by government agencies, such as the Ontario Ministry of the Environment;
- Reviewing literature (journals, reports, books, manuals), particularly publications of the American Water Works Association, United States Academy of Science, International Joint Commission, World Health Organization, on health risks associated with selected priority chemicals in drinking water;
- Reviewing drinking water standards/guidelines and related health criteria of the United States Environmental Protection Agency (USEPA), Health and

Welfare Canada (HWC), World Health Organization (WHO), and related Province/States e.g. Ontario Ministry of the Environment (MOE), New York Commissioner of Health, Wisconsin Department of Natural Resources and Indiana Environmental Management Board.

2.2 TERMINOLOGY

Various government agencies involved in regulating drinking water quality use different terminologies. These are briefly described below:

- The USEPA has developed two types of standards for finished water: primary standards to safeguard human health and secondary standards to preserve the aesthetic quality of water. The primary drinking water standards are set at two levels - Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs). The contaminant concentrations in secondary standards are termed Secondary Maximum Contaminant Levels (SMCLs). Both MCLs and SMCLs are enforceable standards whereas the MCLGs are non-enforceable health goals. However, both MCLs and MCLGs must be proposed at the same time and promulgated simultaneously. The Best Available Technology (BAT) for water treatment to achieve these standards is also to be specified for each contaminant for which a MCL is established (Pontius,1990; Sayer,1988);
- In the United States, individual States may choose to enforce any or all of the primary and secondary regulations of the USEPA. New York State regulates drinking water as the primary agent for the USEPA under Public Health Law through the State Commissioner of Health. Similarly, Wisconsin and Indiana regulate drinking water standards under appropriate acts through the Wisconsin Department of Natural Resources and Indiana Environmental

Management Board respectively (EPA,1988; Env. Reporter,1989);

- Health and Welfare Canada (HWC) has recently revised the non-enforceable Guidelines for Canadian Drinking Water Quality. These guidelines contain Maximum Acceptable Concentrations (MACs) which, if exceeded, may, produce adverse health effects, Interim Maximum Acceptable Concentrations (IMAC) for substances with insufficient toxicological data and Aesthetic Objectives (AO) for aesthetic characteristics. Objective concentrations are set at a level which is the ultimate quality goal for both health and aesthetic purposes. In the previous guidelines, HWC had recommended goals for certain selected chemicals (HWC,1978) but this category was eliminated in the new guidelines (HWC,1989);
- The British North American Act gives Ontario the authority to legislate quality of drinking water through the Ministry of the Environment (MOE). The Ontario Drinking Water Objectives contain Maximum Acceptable Concentrations (MACs) for parameters that cause known or suspected adverse health effects and Maximum Desirable Concentrations (MDCs) for parameters that are aesthetically objectionable or interfere with good water quality control (MOE,1984);
- The World Health Organization (WHO) has proposed Guidelines for Drinking Water Quality which are intended for use by different countries as a basis for development of standards to ensure the safety of the drinking water supplies. The guidelines put forth are not standards (WHO,1984);
- The European Economic Community (EEC) has developed a set of standards for drinking water for all its member countries. The standards address both enforceable Maximum Admissible Concentrations (MACs) and non-enforceable Guide Levels (Sayer,1988).

3.0 HUMAN HEALTH RISKS ASSOCIATED WITH SELECTED PRIORITY CHEMICALS

The procedures used by different organizations in setting drinking water standards are reviewed in this section. The National Research Council (NRC), through its Safe Drinking Water Committee, has so far produced nine volumes of Drinking Water and Health (NRC,1980-89). This Committee has been a pioneer in identifying the toxicological effects of contaminants on human health and assessing associated risk. On the other hand, the USEPA has developed most elaborate procedures to set standards through their Office of Drinking Water (EPA,1990).

The MCLGs established by the USEPA are set at a level at which "no known or anticipated adverse effects on the health of persons occur" and that "allow an adequate margin of safety". The USEPA has set guidelines for classifying contaminants based on the weight of evidence of carcinogenicity as shown in Table 3.1 below (Pontius,1990):

TABLE 3.1 - USEPA WEIGHT-OF-EVIDENCE CRITERIA FOR CLASSIFYING CARCINOGENS

CATEGORY	CRITERION
A	Human Carcinogen (sufficient evidence of carcinogenicity from epidemiologic studies)
B1	Probable Human Carcinogen (limited direct evidence of carcinogenicity to humans)
B2	Probable Human Carcinogen (sufficient evidence from animal studies and inadequate evidence or no data on carcinogenicity to humans)
C	Possible Human Carcinogen (limited evidence from animal studies; no data for humans)
D	Not Classifiable because of inadequate evidence
E	No Evidence of Carcinogenicity in at least two animal tests in different species or in both animal and epidemiologic studies

Based on this evidence, the USEPA Office of Drinking Water uses a three-category approach for setting MCLGs. These categories are:

I. For contaminants with sufficient/strong evidence of carcinogenicity in humans and animals to warrant regulation as known or probable human carcinogens, MCLGs are set at zero. Cancer Groups A and B are included in this category;

II. For contaminants for which there is equivocal evidence of carcinogenicity in animals and that are regulated as possible human carcinogens, MCLGs are based on either (i) Reference Dose (RfD) plus added safety - which is the preferred approach - or (ii) results of quantitative risk assessment within cancer risk range of 10^{-5} to 10^{-6}. Cancer Group C is included in this category;

III. For substances with insufficient or no evidence of carcinogenicity, MCLGs are calculated from RfDs. Cancer Groups D and E are included in this category.

The Reference Dose is a "no effect" level for chronic or lifetime exposure to toxic substances. Available human and animal toxicological data are used to obtain the highest no-observed-adverse-effect level (NOAEL) in mg/day/kg of body mass. Then the RfD is calculated as:

$$RfD = NOAEL \ / \text{ Uncertainty Factor} \quad \ldots 3.1$$

The Uncertainty Factor (UF) accounts for differences in response to toxicity within the human population and between humans and animals. Its value ranges between 10 and 1000, depending primarily on the strength of data available. The Drinking Water Equivalent Level (DWEL) in mg/L represents a lifetime exposure at which adverse effects are not anticipated to occur, assuming 100 percent exposure from drinking

water. The DWEL is calculated as:

$$\text{DWEL (mg/L)} = \frac{\text{RfD x Body Mass (kg)}}{\text{Drinking Water Volume Used (L/d)}} \quad \ldots 3.2$$

The USEPA uses a body mass of 70 kg and drinking water consumption of 2 L/d.

For most contaminants regulated under Category III, it is assumed that 20 % of the dose is contributed through drinking water. Therefore,

$$\text{MCLG} = \text{DWEL} \times 0.2 \quad \ldots 3.3$$

For Category II contaminants, two options are considered:

(i) If sufficient data are available, MCLGs are calculated based on RfD plus an additional UF of 1 to 10 to account for the evidence of possible carcinogenicity; otherwise,

(ii) MCLGs are calculated based on a lifetime risk of 10^{-5} to 10^{-6}. A risk of 10^{-5} means that 1 additional cancer will occur in 100 000 people because of the presence of this contaminant in water. The dose-response data are used to calculate drinking water concentration based on risk level, body mass and daily drinking water consumption.

The MCLs must be set as close as feasible to their respective MCLGs with the use of the best available technology (BAT), taking costs into consideration. Even if MCLGs are set at zero, MCLs for these contaminants cannot be zero, because zero is neither measurable nor achievable using any BAT. The resulting MCLs for Category I contaminants normally fall within the relative risk of 10^{-4} to 10^{-6}.

For guideline values for organic substances that are carcinogenic or suspected to be carcinogenic, WHO uses a risk of less than 1 additional case of cancer per 100 000 population, assuming a consumption of 2 L/d of drinking water by a 70 kg person. For inorganic chemicals, the approach is similar to that used by the USEPA.

The Safe Drinking Water Committee of NRC puts forth suggested no-

adverse-response level (SNARL) for chronic toxicity, based on the assumption that 20 % of the intake was derived from drinking water. An UF of 10 to 1000 is used in the calculations. When there is evidence of carcinogenicity in one or more animal species, numerical risk estimate is made to establish the guidelines for that contaminant in water. A risk of 1 in 100 000 while consuming 1 L of drinking water per day by a 70 kg person is employed.

The adverse health and aesthetic effects of selected chemicals and the criteria used by different organizations to establish drinking water standards are described below:

3.1 BENZENE

Benzene is a petroleum and coal by-product. It is widely used in large quantities as a solvent, as an additive in gasoline and as an intermediate in synthesizing many organic chemicals. It is highly volatile and evaporates rapidly from water.

Benzene produces taste in water at levels of 0.5 to 4.5 mg/L. In chlorinated water, its taste level threshold is lower. In the USSR, the recommended level of benzene in drinking water based on taste is 0.5 mg/L. However, benzene has been placed in Category I by the USEPA and is considered to be carcinogenic to human beings. Acute effects in human beings include nausea, giddiness and headaches while chronic exposure has been reported to produce thrombocytopenia, leucopenia, anaemia and leukaemia. Although some animal studies are equivocal, the evidence for benzene inducing leukaemia in humans is strong. There is also evidence suggesting that benzene can be mutagenic, inducing chromosomal alterations.

Based on the carcinogenicity data available, the USEPA has categorised benzene in Cancer Group A (Table 3.1) and therefore has set the MCLG at zero.

However, considering the BAT and cost, the MCL has been set at 5 ug/L. The WHO has recommended the guideline for benzene at 10 ug/L, based on a risk of 1 in 100 000 (WHO,1984). The Canadian Guidelines recommend a MAC of 5 ug/L based on a cancer risk of 10^{-5} to 10^{-6} (HWC,1989). Best practicable Technology and analytical methods.

3.2 LEAD

Lead is a metal which has been suspected as a poison since ancient times but death due to lead poisoning is rare. The symptoms of acute lead poisoning include vomiting, haemolysis, liver damage and reversible tubular necrosis.The amount of lead in the body is usually quantified in terms of blood lead level (Pb-B) with units of ug/dL.

The USEPA had set the NOAEL for lead in the bloodstream at 15 ug/dL for children and 25 ug/dL for adults in order to prevent inhibition of heme synthesis which can occur at 10 ug/dL Pb-B and neurological disorders which manifest themselves at 15-20 ug/dL in children and at 25-30 ug/dL in adults. Since 20 to 50 % of ingested lead is absorbed, the USEPA has calculated the acceptable daily intake of lead for adults and children as 48 and 19 ug/L respectively. Thus 19 ug/L is considered to be an acceptable daily intake for both groups. Considering that 15 % of ingested lead comes from water, the MCLG for lead has been calculated as 0.15 x 19 = 3 ug/L (EPA,1984). The USEPA has recently established the MCLG for lead at zero because it is classified as belonging to Cancer Group B2 (Table 3.1). A Category I approach has been used in setting standards.

Until recently, all regulatory and advisory agencies had set the acceptable level for lead in drinking water at 50 ug/L so as not to exceed the recommended maximum intake of 3 mg/week from all sources (WHO,1977). However, the USEPA has proposed to lower this level to 5 ug/L effective the middle of 1991 and Health and

Welfare Canada is proposing a MAC of 10 ug/L. In addition, the USEPA is recommending a specific treatment technology to minimize the lead level at the tap.

The lead concentration at the tap may be higher than that of the water leaving the treatment plant. "Aggressive" waters dissolve lead from lead plumbing and lead-soldered joints. Plumbsolvency increases with decreasing pH, decreasing calcium concentration and increasing temperature (WHO,1984).

3.3 ALUMINUM

Aluminum is an engineering material and is also used for food and beverage packing. Aluminum sulfate is added in the treatment of drinking water to coagulate the turbidity in raw water prior to sedimentation and filtration. Although the aluminum level in treated water ranges from <0.01 to 2 mg/L, levels above 0.3 mg/L usually reflect faults in the coagulation, sedimentation or filtration processes (WHO,1984).

About 5 % of aluminum is absorbed by the gut if it is administered as aluminum hydroxide or aluminum carbonate. Aluminum phosphate is not absorbed.

Aluminum is considered to have an effect on brain tissue. Two studies have found elevated aluminum levels in brains of patients who had died of Alzheimer's disease (NRC,1982). Recently, a study of 4100 people aged 40-69 revealed that those who drank water with an aluminum concentration greater than 0.11 mg/L had a 50 % greater chance of developing Alzheimer's disease over those whose water contained less than 0.01 mg/L. In addition, there was a gradient of risk associated with increasing concentrations of aluminum (Martyn et al.,1989). The critics of this study argue that aluminum may enter the drinking water from hot water heaters (Brenner,1989), or pots (Jackson et al.,1989), or by increased absorption of aluminum due to low silicic acid concentrations (Birchall and Chappell,1989).

Aluminum is known to affect chronic dialysis patients. In one study, 13

patients experienced "dialysis dementia" with some symptoms similar to those found in Alzheimer's patients. This occurred three months after the water supplier had adopted aluminum sulfate in its water treatment and aluminum levels in the finished water had increased by 0.15 mg/L (NRC,1982).

At present there are no drinking water standards for aluminum based on adverse health effects. A seven-day no-adverse-response level of 5.0 mg/L in water has been set based on the lethal dose for rats. This level can not be reached in water of normal pH as it exceeds the solubility (NRC,1982). The WHO considered aluminum in water to be non-toxic and set a guideline of 0.2 mg/L. Aluminum oxides precipitate in water pipes and may be disturbed by a sudden change in flow rate resulting in discolouration of the tap water. This usually occurs if the aluminum concentration is greater than 0.1 mg/L (WHO,1984). Similarly, the USEPA has set a SMCL for aluminum in drinking water at 0.05 mg/L based on aesthetic reasons. The USEPA is currently developing a health criterion document for aluminum and has included it in the Drinking Water Priority List of contaminants that may require regulations. Similarly, HWC has included it in the list of chemicals for which the guidelines are being developed.

If the aluminum is regulated in near future based on its adverse health effects, it is expected that the standard will be set close to 5-10 ug/L. The analysis techniques and available technology may be the controlling factors.

3.4 CHLOROFORM

Chloroform is one of the four types of trihalomethanes found in drinking water. The concentration associated with individual lifetime excess cancer risk rate of 10^{-5} is 8 ug/L (WHO,1984; Lappenbush,1986,1988). Considering its carcinogenicity to animals and probable toxicity to humans, the USEPA has classified it as belonging to

Cancer Group B2 and has listed it for regulation. The WHO has established its guidelines at 30 ug/L so as not to compromise the disinfection process and the USEPA is in the process of setting both a MCLG and MCL for chloroform in drinking water. The NRC, WHO and USEPA consider that the concentration should be reduced to a level as low as reasonably achievable depending on the quality of the raw water, without compromising the disinfection process. Further discussion on chloroform is included in the following section on trihalomethanes.

3.5 TRIHALOMETHANES

Trihalomethanes (THMs) are formed during water treatment when the free chlorine used as a disinfectant combines with natural precursors present in raw water. The concentration of THMs depends upon the reaction time, total organic carbon present, pH, temperature and chlorine dose. The common precursors in Great Lakes water are be humic and fulvic acids, algal biomass and algal excretions (Salameh,1987; Martin,1984; Neil,1989). It has been reported that algal substances increase the potential of THM formation. In eutrophic lake water, CO_2 is consumed by the algae, thereby increasing the pH. Furthermore, during water treatment, higher amounts of chlorine are needed to control algal activities and growth. Both an increase in pH and a higher chlorine dose increase the THM forming potential (THMFP) (Neil,1989; Salameh,1987). There is more emphasis placed on THMFP than on actual THM concentration in treated water.

Most recently, proliferation of zebra mussels has been reported in the Great Lakes System. It is believed that the zebra mussels encourage the growth of algae in lake water by reducing the amount of suspended impurities and increasing the penetration of sunlight. Also, the most common method used to control zebra mussels is the addition of chlorine. Consequently, the THMFP in lake water will increase with

time. It is also expected that an increased algal concentration with an increase in chlorine dose will result in a more frequent occurrence of objectionable taste and odour in drinking water (MOE,1988). Last summer, residents of Windsor had complained about the unpalatable taste and odour in their drinking water.

Generally, THMs are a group of chemicals consisting of: Chloroform, Bromodichloromethane, Bromoform and Chlorodibromomethane. The USEPA has classified the first three chemicals as belonging to Cancer Group B2 and the last one in Cancer Group C. All four are listed separately for regulation. The main health effect of THMs is as central nervous system depressants. Epidemiological studies have shown an association between the incidences of 16 different cancers and the levels of THMs in drinking water (WHO,1984). Statistical assessments of risks have been attempted using mathematical models and they indicate that the excess risk for lifetime exposure at 100 ug/L would be of the order of 10^{-4} to 10^{-6} (Martin,1985).

The USEPA is preparing a rule for disinfectants and disinfection byproducts (D-DBP). Promulgation of the rule is planned for 1992. It is anticipated that the new MCL for THMs will be between 25 and 50 ug/L and appropriate BAT will be listed. The key points of D-DBP STRAW rules presented by the USEPA at a public meeting in December, 1989 are shown in Table 3.2 (EPA,1990).

TABLE 3.2- EXTRACTS FROM STRAW RULES PROPOSED BY USEPA FOR THMs

A. MCLs for the following:
- Total Trihalomethanes (TTHMs)
- Chlorine and chloramine

B. List Best Available Technologies:
1. Precursor removal (50 % removal of TTHMFP) using:
   - Conventional treatment modifications
   - Granular Activated Carbon up to 30 minutes empty bed contact time and 3 months regeneration
   - GAC is not universally feasible due to water quality conditions

2. TTHM MCL of 25 ug/L is the lowest that allows continuous use of free chlorine

C. Lead options are:
1. MCLs for TTHMs of 50 ug/L or 25 ug/L

3.6 NITRATES

The major sources of nitrate contamination of drinking water are municipal and industrial wastewater discharges, septic tank systems, and leachate from animal feed lots and refuse dumps. In spite of their many sources, nitrates seldom occur at excessive concentrations in surface waters because they are essential nutrients for all types of aquatic plants and biota.

Nitrates can cause methaemoglobinemia in infants. No cases of methaemoglobinemia have been proved conclusively to be caused by the consumption of water containing less than 10 mg/L of nitrate-N and there are many examples where nitrate concentrations up to 20 mg/L have not produced any clinical effects in infants. The WHO, USEPA, NRC and HWC all specify that total nitrate plus nitrite nitrogen in drinking water should not exceed 10 mg/L as N.

4.0 DRINKING WATER STANDARDS FOR SELECTED PRIORITY CHEMICALS

Most of the industrialized countries in North America and Europe have developed enforceable mandatory drinking water standards to ensure the integrity of public water supplies. In addition, more stringent long term goals have been recommended. Table 4.1 shows both the enforceable standards and recommended goals for the selected priority chemicals as adopted by the USEPA, relevant States, HWC, MOE, WHO, and EEC. It is obvious that there is a remarkable degree of agreement in the levels at which each chemical is regulated. However, recognizing the deleterious health effects of many contaminants, both the enforceable standards and treatment technologies have been modified in recent years or are in the process of review. The significance of deviations in certain levels are discussed below.

TABLE 4.1 - CURRENT DRINKING WATER STANDARDS/GOALS FOR THE SELECTED PRIORITY CHEMICALS

PARAMETER	HWC GUIDE-LINES	MOE MAC	USEPA MCL	USEPA MCLG	STATES[a] MCL	WHO GUIDE-LINES	EEC MAC	EEC GL
BENZENE (ug/L)	5	NS	5	0	5	10	NS	
LEAD (mg/L)	~~0.05~~ (0.01)[d]	0.05	0.05 (0.005)[d]	0	0.05	0.05	0.05	
ALUMINUM (mg/L)	NS	NS	0.05[f] (SMCL)		NS	0.2	0.2	0.05
CHLOROFORM (mg/L)	NS (0.05)	NS	NS[g]		NS	0.03	NS	
THM (mg/L)	0.35[g] (0.04)	0.35[g]	0.10[g]		0.10[g]	0.03[c]	0.001	
NITRATES (mg/L as N)	10.0	10.0	10.0[e]	10.0[e]	10.0	10.0	50[h]	25[h]

NS = No Standard; a = Wisconsin, Indiana, New York; b = Tentative; c = for chloroform only; d = Proposed, final adoption in near future; e = Includes nitrites as N; f = Proposed SMCL, final adoption in near future; g = Under review; h = mg/L as nitrates

BENZENE: Benzene is carcinogenic and it is expected that all regulatory agencies will adopt 0 to 5 ug/L as a standard based on available treatment technology and the ability to detect it at low concentrations.

LEAD: Although until recently lead has been regulated at 50 ug/L, both Canadian and the US governments are proposing to lower it because of its acute toxicity. It is expected that eventually lead will be regulated at 5 ug/L at the tap. Proper removal technology and analytical techniques will have to be developed to achieve that level.

ALUMINUM: At present, aluminum is regulated based on aesthetic reasons. However, there is sufficient concern about its adverse health effects and it is expected that within the next few years, aluminum will be regulated as a toxic chemical and its

level may be set around 5 ug/L.

CHLOROFORM: At present, only WHO has set guidelines for chloroform and these guidelines are influenced by the philosophy that chlorination for disinfection should not be compromised. The USEPA has classified it as a probable carcinogen and will soon regulate it. It is expected that chloroform will eventually be regulated at 10 to 20 ug/L.

TRIHALOMETHANES: THMs include several compounds with probable carcinogenicity to humans. There are considerable variations in levels at which THMs are regulated in different countries (Table 4.2). The main reasons for these variations are: (i) their abundance in chlorinated surface waters, (ii) lack of availability of economical technology, and (iii) lack of acceptable evidence of their carcinogenic effects. It is expected that in the next one to two years, the USEPA will set standards for THMs at 25 to 50 ug/L and suggest the BAT and the other countries in the world will follow the trend. It is difficult to explain why Canadian guidelines are out of step with the rest of the world.

TABLE 4.2 - THM STANDARDS/GUIDELINES USED BY DIFFERENT REGULATORY AGENCIES

CANADA /ONTARIO - still allows up to 350 ug/L. In the 1978 Canadian Guidelines, Goal was set at 5 ug/L (HWC,1978)[a].

EEC - Recommends a desirable value of 1 ug/L.[b]

SWEDEN - Recommends a desirable level of 1 ug/L.[b]

FEDERAL REPUBLIC GERMANY - has set 25 ug/L as the level for treated water.[b]

USA - Originally proposed an interim primary MCL of 350 ug/L. In 1979, it was lowered to 100 ug/L. It is expected to be lowered further to 25-50 ug/L in 1992.

a = HWC has dropped Goals as a category in the new guidelines (HWC,1989); b = (Salameh, 1987)

NITRATES: The nitrates (including nitrites) are currently regulated at 10 mg/L as N.

5.0 WATER TREATMENT TECHNOLOGIES AVAILABLE TO ACHIEVE STANDARDS

Both the United States Environmental Protection Agency and Health and Welfare Canada suggest treatment methods that can be used to lower or remove chemicals that are regulated. Based on this information (EPA,1990; HWC,1989), the available technologies that have significant influences in controlling the selected chemicals are listed below:

5.1 BENZENE

Benzene is a highly volatile organic compound and can be significantly reduced by Packed Tower Aeration and Granular Activated Carbon. Both PTA and GAC are expensive treatment methods and are not used in conventional water treatment plants. Both of these are considered to be economically feasible.

5.2 LEAD

The conventional coagulation and lime softening methods have been able to keep lead levels below current standards. However, for the newly proposed standards, the USEPA is proposing required corrosion control. Minimum corrosiveness in water is achieved by holding pH above 8 and moderating alkalinity and hardness (> 30 mg/L as $CaCO_3$) (Morse, 1988). Thus, technology for regulating lead at the proposed levels already exists and is economically feasible.

Ion exchange and reverse osmosis processes can reduce the lead concentrations to almost zero level, but these are more expensive methods (MOE, 1987).

5.3 ALUMINUM

Experience with existing water treatment plants that have been using alum as a coagulant shows that it may be possible to keep aluminum levels to below 0.1 mg/L simply by good control of the coagulation, flocculation, sedimentation and filtration processes (WHO,1984). However, for lowering aluminum below this level, alum may have to be replaced with other coagulants such as ferric salts. Also, appropriate technology will have to be developed for the removal of aluminum from water.

5.4 CHLOROFORM

The treatment technologies available for controlling chloroform in drinking water are similar to those available for THM control. These technologies are discussed in the next section.

5.5 TRIHALOMETHANES

The following methods have been suggested for reducing THM concentrations in drinking water (DWHE Task Force,1989):

- Process modifications - specially using alternative disinfectants in the prechlorination stage
- Precursor removal either by improving the conventional treatment methods and/or using GAC before chlorination
- Replacement of chlorine with alternate disinfectants after filtration
- Removal of THMs by aeration or other methods

To achieve THM levels below 25 ug/L, chlorine will have to be replaced with alternative disinfectants. Although the USEPA recommends granular activated carbon to be an effective and economical method for controlling THMs, there has been lot of opposition to its use (DWHE Task Force,1989). GAC may become popular in the future if more organic chemicals are added to the list of toxic chemicals.

5.6 NITRATES

If nitrates exceed the allowable limits in drinking water, then ion exchange and reverse osmosis methods are available for their removal. Both methods are expensive but economically feasible (EPA,1985).

6.0 REVIEW OF WATER QUALITY DATA FROM SELECTED URBAN AREAS

The individual communities and the related regulatory agencies were contacted for collecting relevant data for the selected chemicals. It was found that the three communities in Ontario started collecting data on most of these chemicals on a monthly basis in 1986. Very little information is available before that time. The three communities in the United States have been analyzing for some of these chemicals on an irregular basis. The information used for this report is tabulated in Table 6.1.

TABLE 6.1 - SUMMARY OF DATA USED FOR THIS REPORT

PERIOD	TORONTO 1	TORONTO 2	TORONTO 3	THUNDER BAY	WINDSOR	MILWAUKEE	GARY	ROCHESTER
1990	x	x	x	x	x	y	y	x
1989	x	x	x	x	x	y	y	x
1988	x	x	x	x	x	y	y	x
1987	x	x	x	x	x	y	y	x
1986	x	x	x	x	x	y	y	x

x = Raw and treated water data: monthly (Canadian) or quarterly (US);
y = Treated water data only

Some treated water data was measured in the water distribution system as opposed to the water treatment plant outlet. This data was combined with the plant outlet data. Such was the case for all data from Gary, the lead data from Milwaukee and the aluminum, lead, nitrate and THM data from Rochester.

Both raw and treated water data were collected in order to estimate the effectiveness of existing treatment processes in removing or forming the chemicals under review. The treatment processes currently used by the selected communities are shown in Table 6.2.

TABLE 6.2 - TREATMENT PROCESSES CURRENTLY USED BY THE SELECTED COMMUNITIES

WATER TREATMENT PLANT	TREATMENT PROCESSES USED					
	PRE-CHLOR	COAG/ FLOCC	SEDIM-ENT	FILTR-ATION	POST-CHLOR	OTHER TREATMENTS
TORONTO 1	+	+		+	+	F, SO , AMM
TORONTO 2	+	+	+	+	+	F, SO , AMM
TORONTO 3	+	+	+	+	+	F, SO , AMM
THUNDER BAY	+	+		+	+	Polymer
WINDSOR	+	+	+	+	+	Polymer, F
MILWAUKEE	+	+	+	+	+	F, AMM, PAC
GARY	+	+	+	+	+	F, ZOP, AMM
ROCHESTER	+	+		+	+	Polymer, F, PP, PAC

PRECHLOR = Prechlorination; COAG/FLOCC = Coagulation and Flocculation; SEDIMENT = Sedimentation; POST-CHLOR = Post-chlorination; F = Fluoride addition; SO = Sulfur dioxide addition; AMM = Ammoniation; ZOP = Zinc Orthophosphate addition; PP = Potassium permanganate addition; PAC = Powdered Activated Carbon addition prior to filtration

Certain salient features of these treatment plants which have significance in this report are discussed below:

6.1 TORONTO, ONTARIO

Toronto has three water treatment plants all of which receive raw water from Lake Ontario. These WTP are:

TORONTO 1 = TORONTO EASTERLY
TORONTO 2 = TORONTO (R.L. CLARK)
TORONTO 3 = TORONTO (R.C. HARRIS)

Essentially the same treatment is provided in all three plants. Superchlorination is used for disinfection and for taste and odour control. Sulfur dioxide is used as a

dechlorinator and ammoniation is used to produce a long lasting chloramine (chlorine + ammonia) residual in the distribution system (OME, 1988). The use of chloramine has been shown to reduce the formation of THMs.

6.2 THUNDER BAY, ONTARIO

Thunder Bay has two water treatment plants but only one (Bare Point) has been considered in this study because the other plant does not draw water from the Great Lakes. This plant is a conventional water treatment plant.

6.3 WINDSOR, ONTARIO

This water treatment plant provides conventional treatment with the exception that in the Summer of 1990 PAC was added to control taste and odour.

6.4 MILWAUKEE, WISCONSIN

Both the Linnwood and Howard Avenue water treatment plants use ammoniation and add PAC in the summer for taste and odour control. The Howard Avenue plant uses potassium permanganate in addition to chlorine for pretreatment oxidation. Linnwood does not employ prechlorination. Data from both plants have been combined in this study.

6.5 GARY, INDIANA

The water treatment plant in Gary is a conventional plant with the exception that zinc orthophosphate is added for corrosion control. The chlorine dose is reduced by the addition of ammonia which provides a longer-lasting residual.

6.6 ROCHESTER, NEW YORK

The treatment plant in the town of Greece has the capability of chlorinating at several points. Typically, chlorine is added before and after filtration. Potassium

permanganate is used as a raw water oxidant resulting in less odour than when chlorine is used. PAC is added to control taste and odour when the raw water temperature exceeds 50°C.

6.7 ANALYSIS OF DATA

The raw and treated water data collected from the above plants were analyzed for each chemical as described below:

- The mean value, highest value, lowest value and the number of values are reported in Tables 6.3 to 6.8 respectively for Benzene, Lead, Aluminum, Chloroform, Trihalomethanes and Nitrates in raw water. Where the values were below the detection limit (BDL), the numerical value used for calculating the average was one half of the detection limit. When all values for one location for a year were BDL, the average is reported as less than the detection limit value.
- The mean value, highest value, lowest value and the number of values are reported in Tables 6.9 to 6.14 respectively for Benzene, Lead, Aluminum, Chloroform, Trihalomethanes and Nitrates in treated water. The data were analyzed as explained above.
- The raw water and treated water data for the entire period studied for a particular chemical at specific location were pooled and ranked in descending order. The frequency of exceedance was calculated and the results have been plotted on log-probability paper in Figures 6.1 to 6.4. For lead, chloroform and trihalomethanes (Figures 6.1, 6.3 and 6.4) only values exceeding 1 ug/L are plotted. For aluminum (Figure 6.2), only values exceeding 10 ug/L are plotted.

TABLE 6.3 - Benzene in Raw Water (ug/L)

Year	Ontario										Wisconsin	Indiana	New York	
	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee	Gary	Rochester	
1990	0.03	0.05 10 <0.05	0.03	0.05 6 <0.05	0.03	0.05 6 <0.05	<0.05	<0.05 6 <0.05	<0.05	<0.05 6 <0.05	N.A.	N.A.	<0.05	<0.5 1 <0.5
1989	<0.05	<0.05 9 <0.05	0.04	0.10 11 <0.05	<0.05	<0.05 12 <0.05	<0.05	<0.05 12 <0.05	0.03	0.05 12 <0.05	N.A.	N.A.	<0.05	<0.5 1 <0.5
1988		N.A.	<0.05	<0.05 12 <0.05	<0.05	<0.05 12 <0.05	<0.05	<0.05 10 <0.05	<0.05	<0.05 11 <0.05	N.A.	N.A.	<0.05	<0.5 2 <0.5
1987		N.A.	<0.05	<0.05 13 <0.05	<0.05	<0.05 12 <0.05		N.A.	<0.05	<0.05 12 <0.05	N.A.	N.A.	0.8	<2 2 <1
1986		N.A.		N.A.		N.A.		N.A.		N.A.	N.A.	N.A.	0.8	<2 3 <1

KEY

Average Value	Highest Value Number of Values Lowest Value

N.A. = Not Available

TABLE 6.4 - Lead in Raw Water (ug/L)

	Ontario										Wisconsin	Indiana		New York	
Year	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee	Gary		Rochester	
		0.67		11.00		0.70		1.50		0.81			<6		3.0
1990	0.12	11	5.30	5	0.45	6	0.63	6	0.44	6	N.A.	<6	6	1.8	2
		<0.05		1.30		0.30		0.21		0.13			<6		<1
		0.26		51.00		1.09		0.95		0.94			10		<5
1989	0.08	11	8.58	12	0.59	12	0.58	12	0.49	12	N.A.	4	10	<5	2
		<0.02		1.10		0.19		0.22		0.13			<6		<5
		0.20		20.00		0.54		0.88		0.5			31		
1988	0.11	4	3.84	13	0.26	12	0.37	12	0.28	12	N.A.	6	12	N.A.	
		<0.05		0.43		0.10		0.15		0.2			<6		
				7		4		6		4			7		<20
1987	N.A.		3	13	2	13	2	12	2	12	N.A.	4	11	7.5	2
				<3		<3		<3		<3			<6		<10
				460									<10		<50
1986	N.A.		106	7	N.A.		N.A.		N.A.		N.A.	<10	11	13.7	3
				11									<10		6.0

KEY

Average Value	Highest Value Number of Values Lowest Value

N.A. = Not Available

TABLE 6.5 - Aluminum in Raw Water (ug/L)

	Ontario										Wisconsin		Indiana	New York	
Year	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee		Gary	Rochester	
1990	66.00 22.62 11 7.60		280.00 117.20 5 29.00		41.00 25.417 6 9.50		89.00 36.9 6 9.40		48.00 19.65 6 4.30		150 50 44 10		N.A.	< 50 < 50 2 < 50	
1989	22.00 12.41 11 6.80		130.00 57.50 12 19.00		20.00 10.85 12 6.15		120.00 26.40 12 7.00		81.00 24.24 12 6.73		50 27 5 < 10		N.A.	N.A.	
1988	21.00 13.73 4 6.10		490.00 147.70 13 10.08		37.00 13.08 12 3.90		42.92 20.26 12 5.92		36.00 13.13 12 3.90		80 29 4 < 10		N.A.	N.A.	
1987	N.A.		2500 476 13 69		220 36 12 2		71 34 12 8		170 43 12 8		50 30 3 20		N.A.	80.0 70.0 2 60.0	
1986	N.A.		1100 341 11 54		N.A.		N.A.		N.A.		40 20 4 < 10		N.A.	120.0 58.3 3 < 10	

KEY

	Highest Value
Average Value	Number of Values
	Lowest Value

N.A. = Not Available

TABLE 6.6 - Chloroform in Raw Water (ug/L)

Year	Ontario										Wisconsin	Indiana	New York	
	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee	Gary	Rochester	
1990	1.0 0.2 10 <0.1		<0.1 <0.1 6 <0.1		3.6 0.7 6 <0.1		0.1 0.1 6 <0.1		<0.1 <0.1 5 <0.1		N.A.	N.A.	<0.5 <0.5 2 <0.5	
1989	1.3 0.4 9 <0.1		0.7 0.2 10 <0.1		2.4 0.3 12 <0.1		0.2 0.1 12 <0.1		0.2 0.1 12 <0.1		N.A.	N.A.	N.A.	
1988	0.4 0.2 4 <0.1		0.3 0.1 12 <0.1		2.3 0.5 11 <0.1		0.3 0.1 10 <0.1		0.4 0.1 11 <0.1		N.A.	N.A.	N.A.	
1987	N.A.		0.3 0.1 12 <0.1		0.2 0.1 12 <0.1		0.3 0.1 10 <0.1		0.2 0.1 12 <0.1		N.A.	N.A.	<1 <1 3 <1	
1986	N.A.		13.0 13.0 1 13.0		N.A.		N.A.		N.A.		N.A.	N.A.	<1 <1 2 <1	
1985	N.A.		N.A.		N.A.		N.A.		N.A.		N.A.	N.A.	N.A.	
1984	N.A.		N.A.		N.A.		N.A.		N.A.		N.A.	N.A.	N.A.	
1982	N.A.		N.A.		N.A.		N.A.		N.A.		N.A.	N.A.	N.A.	

TABLE 6.7 - Trihalomethanes in Raw Water (ug/L)

	Ontario												Wisconsin		Indiana		New York	
Year	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee		Gary		Rochester	
1990	<0.5	<0.5	<0.5	<0.5	1.5	7.4	<0.5	<0.5	<0.5	<0.5	N.A.		N.A.		<2	<2
		6		6		6		6		5						2
		<0.5		<0.5		<0.5		<0.5		<0.5						<2
1989	0.4	0.5	0.3	0.7	0.7	5.8	<0.5	<0.5	<0.5	<0.5	N.A.		N.A.		<2	<2
		12.0		10		13		12		12						1
		0.1		<0.5		<0.5		<0.5		<0.5						<2
1988	<0.5	<0.5	0.3	0.3	1.0	6.1	<0.5	<0.5	0.3	1.1	<9	<9	N.A.		<2	<2
		4		12		11		10		11		4				2
		<0.5		<0.5		<0.5		<0.5		<0.5		<9				<2
1987	N.A.		0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	<9	<9	N.A.		3.5	6.5
				12		12		10		12		7				3
				<0.5		<0.5		<0.5		<0.5		<9				<4
1986	N.A.		20.0	20.0	N.A.		N.A.		N.A.		<9	<9	N.A.		2.8	<6
				1								8				3
				20.0								<9				<5

KEY

	Highest Value
Average Value	Number of Values
	Lowest Value

N.A. = Not Available

TABLE 6.8 - Nitrates in Raw Water (mg N/L)

	Ontario										Wisconsin		Indiana		New York	
Year	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee		Gary		Rochester	
1990	0.50 0.36 6 0.25		1.40 0.63 5 0.28		0.46 0.35 6 0.24		0.50 0.36 6 0.25		0.41 0.34 6 0.25		0.75 0.31 10 0.16		0.30 0.30 6 0.30		0.4 0.3 2 0.2	
1989	0.49 0.35 12 0.14		1.23 0.47 12 0.24		0.40 0.33 12 0.16		0.49 0.35 12 0.14		0.42 0.32 12 0.15		9.40 2.21 7 0.19		0.40 0.30 12 0.20		0.32 0.32 2 0.32	
1988	0.30 0.28 4 0.26		2.27 0.82 13 0.11		0.42 0.36 12 0.27		0.48 0.40 12 0.33		0.42 0.37 12 0.30		2.00 0.72 7 0.17		0.80 0.38 13 0.30		N.A.	
1987	N.A.		1.74 0.50 13 0.18		0.44 0.34 12 0.16		0.56 0.39 12 0.19		0.47 0.35 12 0.16		0.88 0.41 8 < 0.01		0.40 0.31 11 0.20		0.99 0.63 2 0.26	
1986	N.A.		1.10 0.45 9 0.22		N.A.		N.A.		N.A.		0.82 0.29 13 0.10		0.40 0.28 12 0.20		0.29 0.25 2 0.21	

KEY

Average Value	Highest Value Number of Values Lowest Value

N.A. = Not Available

TABLE 6.9 - Benzene in Treated Water (ug/L)

	Ontario					Wisconsin	Indiana	New York
Year	Thunder Bay (Bare Point)	Windsor	Toronto (Easterly)	Toronto (R.L.Clark)	Toronto (R.C.Harris)	Milwaukee	Gary	Rochester
1990	0.05 0.03 11 <0.05	0.05 0.03 6 <0.05	0.15 0.05 6 <0.05	0.10 0.04 6 <0.05	0.10 0.04 6 <0.05	N.A.	<1.0 <1.0 6 <1.0	N.A.
1989	0.10 0.03 9 <0.05	0.10 0.04 12 <0.05	<0.05 <0.05 12 <0.05	<0.05 <0.05 12 <0.05	<0.05 <0.05 12 <0.05	BDL BDL 4 BDL	<1 <1.0 5 <1.0	N.A.
1988	N.A.	0.05 0.03 12 <0.05	<0.05 <0.05 12 <0.05	0.10 0.04 10 <0.05	<0.05 <0.05 10 <0.05	N.A.	<1 0.4 5 <0.7	N.A.
1987	N.A.	0.2 0.05 13 <0.05	<0.05 <0.05 12 <0.05	N.A.	<0.05 <0.05 9 <0.05	N.A.	N.A.	<2 0.8 2 <1
1986	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	7.0 1.7 6 <1

KEY

Average Value	Highest Value Number of Values Lowest Value

N.A. = Not Available

TABLE 6.10 - Lead in Treated Water (ug/L)

Year	Ontario										Wisconsin		Indiana		New York	
	Thunder Bay (Bare Point)		Windsor		Toronto (Easterly)		Toronto (R.L.Clark)		Toronto (R.C.Harris)		Milwaukee		Gary		Rochester	
1990	0.04	0.07 11 <0.05	0.06	0.12 5 <0.05	0.37	0.49 6 0.23	0.08	0.14 6 <0.05	0.20	0.41 6 0.07	N.A.		<1.0	<1.0 1 <1.0	2.1	10.0 7 <1
1989	0.07	0.26 11 <0.05	0.15	0.51 12 <0.02	0.98	2.80 12 0.35	0.17	0.60 12 <0.05	0.32	0.69 12 0.12	<3	<3 1 <3	<6.0	<6.0 1 <6.0	N.A.	
1988	0.08	0.17 4 <0.05	0.54	4.90 13 <0.05	0.36	0.56 12 0.17	0.08	0.11 11 <0.05	0.27	0.62 12 0.04	0.3	0.3 1 0.3	2.2	<6.0 3 <1	<5	<5 1 <5
1987	N.A.		756	9800 13 <3	2	4 11 <3	2	4 12 <3	2	6 10 <3	<0.5	<0.5 1 <0.5	4.8	6.6 2 <6	3.8	<10 2 <5
1986	N.A.		24	42 2 5	N.A.		N.A.		N.A.		<3	<3 1 <3	3.5	<10 3 <1	10.7	<50 4 <5
1985	N.A.		N.A.		N.A.		N.A.		N.A.		24.5	28.0 2 21.0	N.A.		N.A.	
1984	N.A.		N.A.		N.A.		N.A.		N.A.		22.5	25.0 2 20.0	N.A.		N.A.	
1982	N.A.		N.A.		N.A.		N.A.		N.A.		<3	<3 1 <3	N.A.		N.A.	
1981	N.A.		N.A.		N.A.		N.A.		N.A.		9.3	17.0 2 <3	N.A.		N.A.	
1980	N.A.		N.A.		N.A.		N.A.		N.A.		<3	<3 1 <3	N.A.		N.A.	
1978	N.A.		N.A.		N.A.		N.A.		N.A.		<3	<3 1 <3	N.A.		N.A.	
1977	N.A.		N.A.		N.A.		N.A.		N.A.		3	3 1 3	N.A.		N.A.	
1975	N.A.		N.A.		N.A.		N.A.		N.A.		<3	<3 3 <3	N.A.		N.A.	

TABLE 6.11 - Aluminum in Treated Water (ug/L)

	Ontario																Wisconsin	Indiana			New York	
Year	Thunder Bay (Bare Point)			Windsor			Toronto (Easterly)			Toronto (R.L.Clark)			Toronto (R.C.Harris)				Milwaukee	Gary			Rochester	
		56.00			140.00			250.00			290.00			240.00						145.0			< 50.0
1990	31.82	11		127.40	5		119.83	6		139.33	6		116.00	6			N.A.	145.0	1		< 50.0	9
		20.00			77.00			61.00			77.00			80.00						145.0			< 50.0
		83.00			250.00			210.00			250.00			300.00						200.0			
1989	30.02	11		142.83	12		99.01	12		114.67	12		143.94	12			N.A.	200.0	1			N.A.
		8.20			65.00			57.00			46.00			84.68						200.0			
		50.00			170.00			110.00			127.60			190.00						310.0			
1988	26.75	4		112.69	13		64.40	12		80.25	11		90.50	12			N.A.	195.3	3			N.A.
		15.00			40.00			46.00			58.00			55.00						56.0			
					240			27			220			340						140.0			70.0
1987		N.A.		138	13		96	11		105	12		133	10			N.A.	133.0	2		70.0	1
					71			38			61			70						126.0			70.0
					5100															100.0			250.0
1986		N.A.		799	10			N.A.			N.A.			N.A.				N.A.	85.3	3		115.0	4
					91															56.0			< 10.0

KEY

	Highest Value
Average Value	Number of Values
	Lowest Value

N.A. = Not Available

TABLE 6.12 - Chloroform in Treated Water (ug/L)

	Ontario					Wisconsin	Indiana	New York
Year	Thunder Bay (Bare Point)	Windsor	Toronto (Easterly)	Toronto (R.L.Clark)	Toronto (R.C.Harris)	Milwaukee	Gary	Rochester
1990	48.1 29.4 11 16.4	30.5 24.2 6 16.7	10.9 7.1 6 5.4	8.5 6.7 6 5.0	8.9 6.2 6 4.5	8.8 6.7 8 3.3	42.8 16.0 5 14.7	22.0 20.0 2 18.0
1989	52.0 40.0 9 31.0	35.5 25.1 12 15.4	10.1 6.9 12 4.8	12.6 7.7 12 5.2	14.6 7.8 12 4.9	11.0 7.5 6 5.9	18.3 11.2 6 3.8	N.A.
1988	46.3 40.9 4 36.2	51.1 30.7 12 17.2	15.2 8.6 11 5.4	17.5 8.4 10 <0.1	18.0 8.9 10 5.7	<1.0 <1.0 3 <1.0	13.0 7.8 6 3.6	N.A.
1987	N.A.	45.4 33.2 13 22.0	12.2 8.6 12 6	18.0 9.5 12 6.0	13.8 8.6 9 6.0	N.A.	12.0 7.7 6 4.0	18.0 10.6 2 3.2
1986	N.A.	84.0 47.8 9 27.0	N.A.	N.A.	N.A.	N.A.	14.0 9.2 5 4.0	26.0 13.4 6 4.0
1985	N.A.	N.A.	N.A.	N.A.	N.A.	2.0 2.0 1 2.0	N.A.	N.A.
1984	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
1982	N.A.	N.A.	N.A.	N.A.	N.A.	8.5 4.5 2 0.5	N.A.	N.A.

TABLE 6.13 - Trihalomethanes in Treated Water (ug/L)

Year	Ontario					Wisconsin	Indiana	New York
	Thunder Bay (Bare Point)	Windsor	Toronto (Easterly)	Toronto (R.L.Clark)	Toronto (R.C.Harris)	Milwaukee	Gary	Rochester
1990	52.2 35.2 11 20.7	46.9 38.8 6 34.0	23.7 17.2 6 13.6	20.8 16.3 6 14.2	19.8 16.4 6 13.5	19.0 12.4 8 10.2	56.1 24.9 5 10.5	48.0 27.5 17 9.0
1989	57.4 44.9 9 35.9	54.1 42.1 12 28.1	23.2 17.6 12 13.8	32.1 19.2 12 14.2	29.5 19.6 12 15.6	19.0 14.7 6 11.3	30.3 19.8 6 8.9	37.0 24.4 11 10.0
1988	51.2 45.3 4 40.0	70.6 48.9 12 27.5	34.6 21.3 11 16.1	43.2 23.4 10 15.8	39.6 22.4 10 14.8	<9.0 <9.0 3 <9.0	22.0 15.4 6 8.4	41.0 24.8 17 13.0
1987	N.A.	68.5 53.6 13 41.7	25.1 19.9 12 16.0	37.0 21.7 12 16.0	33.2 21.1 9 16.0	N.A.	23.0 15.2 6 9.0	24.0 15.0 2 6.0
1986	N.A.	106.0 65.4 9 40.0	N.A.	N.A.	N.A.	N.A.	23.0 17.0 5 7.0	47.0 24.8 5 7.0
1985	N.A.	N.A.	N.A.	N.A.	N.A.	2.0 2.0 1 2.0	N.A.	N.A.
1984	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
1982	N.A.	N.A.	N.A.	N.A.	N.A.	15.3 9.4 2 3.5	N.A.	N.A.

TABLE 6.14 - Nitrates in Treated Water (mg N/L)

	Ontario												Wisconsin			Indiana			New York		
Year	Thunder Bay (Bare Point)			Windsor			Toronto (Easterly)			Toronto (R.L.Clark)			Toronto (R.C.Harris)			Milwaukee			Gary			Rochester		
1990	0.32	0.35 11 0.29		0.63	1.40 5 0.28		0.35	0.46 6 0.22		0.36	0.51 6 0.24		0.35	0.40 6 0.26		N.A.			N.A.			0.3	0.4 7 <0.2	
1989	0.29	0.33 11 0.17		0.46	1.38 12 0.24		0.33	0.41 12 0.16		0.35	0.45 12 0.17		0.33	0.40 12 0.15		0.2	0.2 1 0.2		0.4	0.4 1 0.4			N.A.	
1988	0.29	0.32 4 0.28		0.82	2.13 13 0.08		0.37	0.44 11 0.29		0.39	0.46 11 0.32		0.37	0.43 12 0.30		0.3	0.3 1 0.3		0.2	0.2 3 0.2		0.67	0.67 1 0.67	
1987		N.A.		0.47	1.21 13 0.20		0.35	0.47 11 0.17		0.37	0.46 12 0.19		0.37	0.47 9 0.19		<0.5	<0.5 1 <0.5		0.2	0.2 1 0.2		0.39	0.41 2 0.37	
1986		N.A.		0.43	0.90 10 0.20			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5		0.3	0.3 2 0.3		0.20	0.34 3 <0.10	
1985		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1984		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1982		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1981		N.A.			N.A.			N.A.			N.A.			N.A.		0.4	0.5 2 <0.5			N.A.			N.A.	
1980		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1978		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1977		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 1 <0.5			N.A.			N.A.	
1975		N.A.			N.A.			N.A.			N.A.			N.A.		<0.5	<0.5 2 <0.5			N.A.			N.A.	

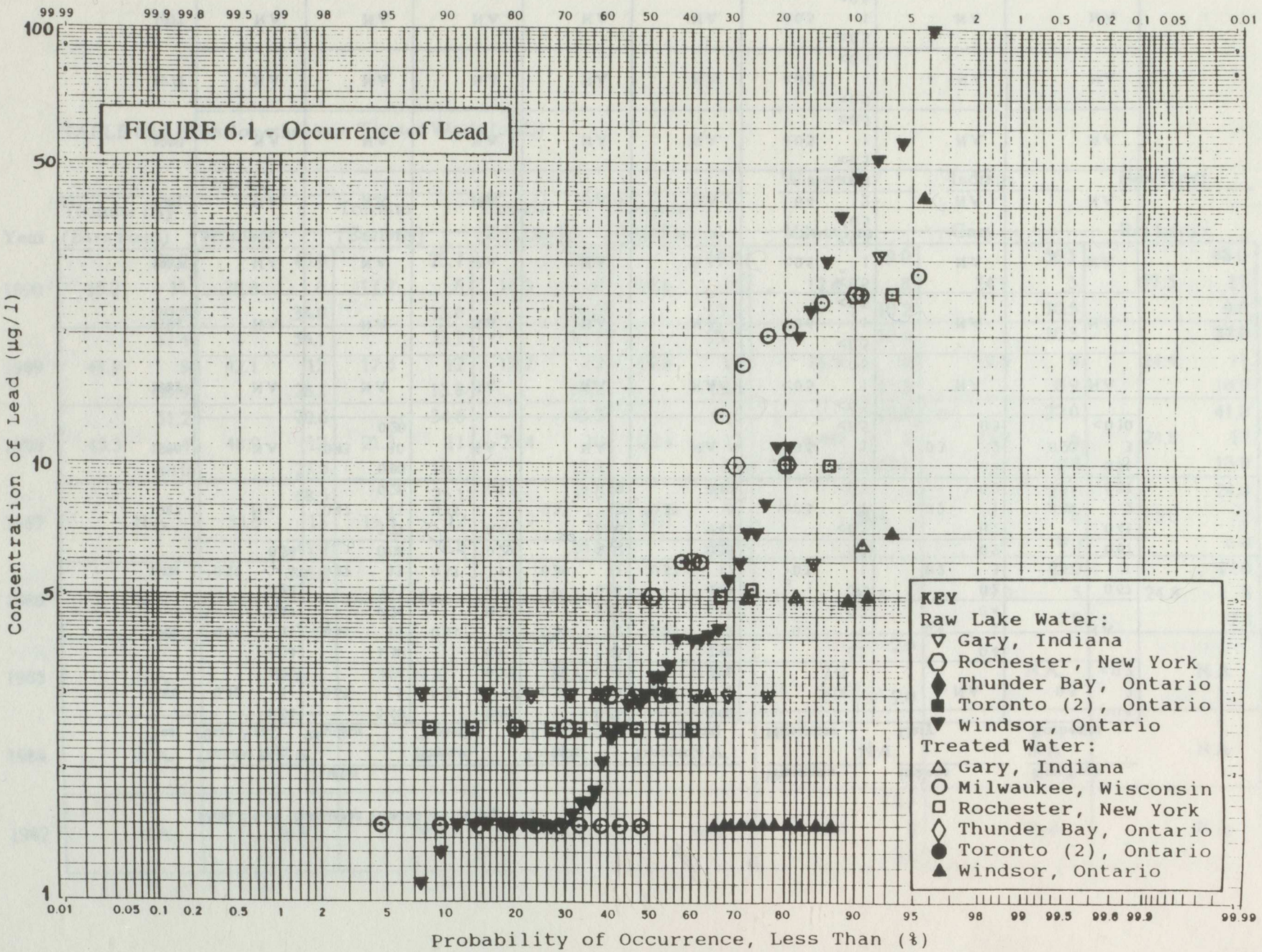


FIGURE 6.1 - Occurrence of Lead
Concentration of Lead (µg/l)
Probability of Occurrence, Less Than (%)
KEY
Raw Lake Water:
Gary, Indiana
Rochester, New York
Thunder Bay, Ontario
Toronto (2), Ontario
Windsor, Ontario
Treated Water:
Gary, Indiana
Milwaukee, Wisconsin
Rochester, New York
Thunder Bay, Ontario
Toronto (2), Ontario
Windsor, Ontario

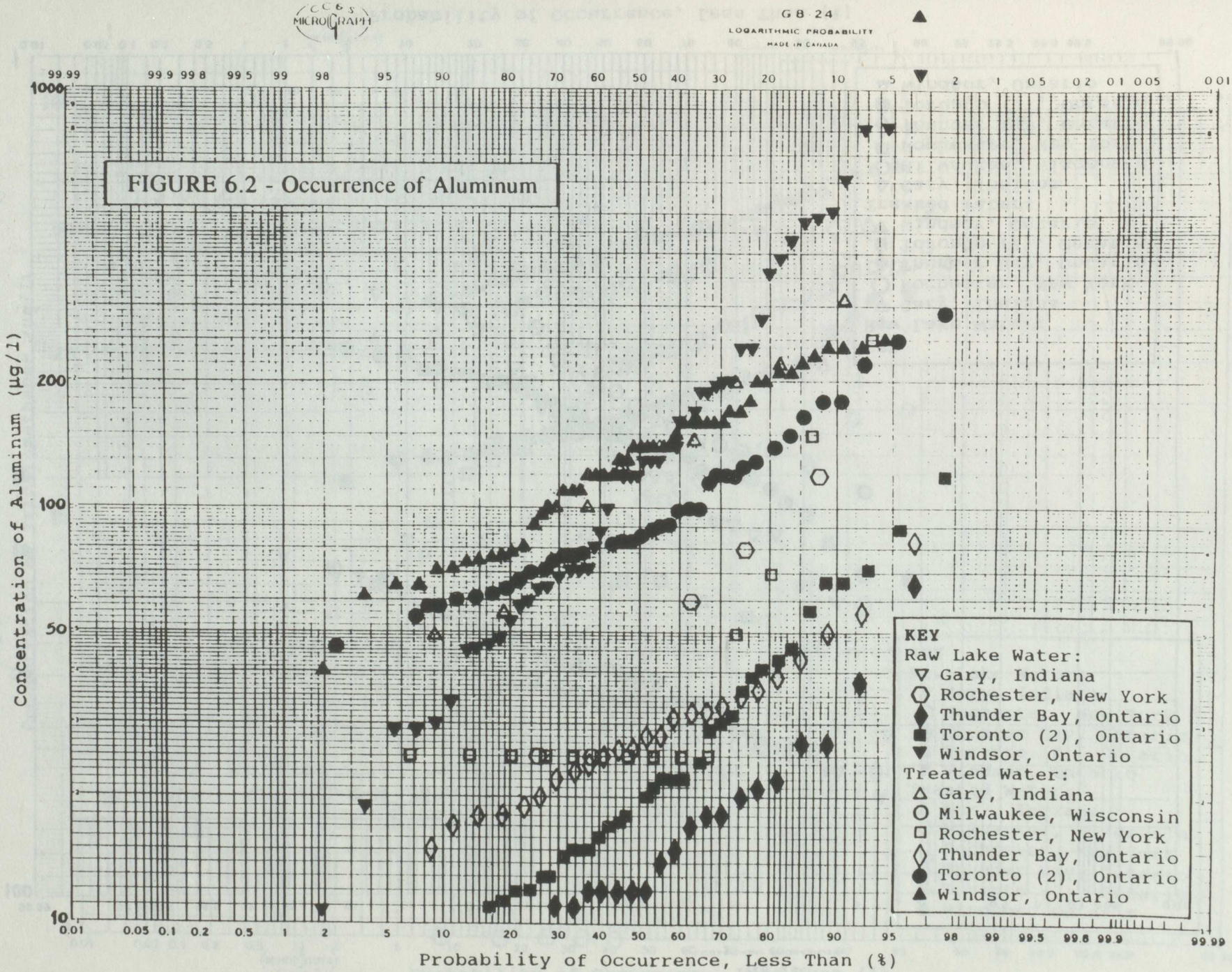
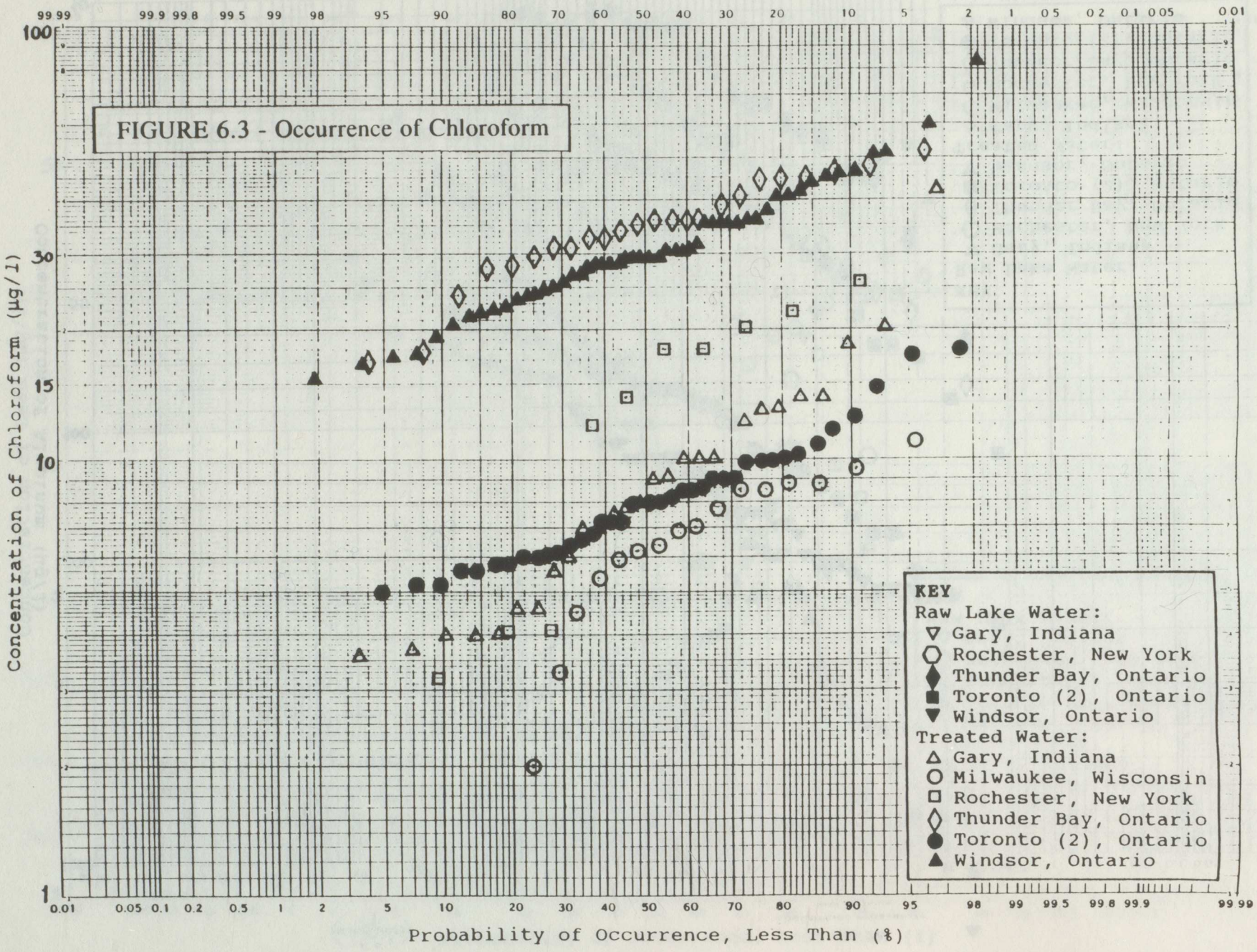


FIGURE 6.2 - Occurrence of Aluminum
Concentration of Aluminum (µg/l)
Probability of Occurrence, Less Than (%)
KEY
Raw Lake Water:
Gary, Indiana
Rochester, New York
Thunder Bay, Ontario
Toronto (2), Ontario
Windsor, Ontario
Treated Water:
Gary, Indiana
Milwaukee, Wisconsin
Rochester, New York
Thunder Bay, Ontario
Toronto (2), Ontario
Windsor, Ontario



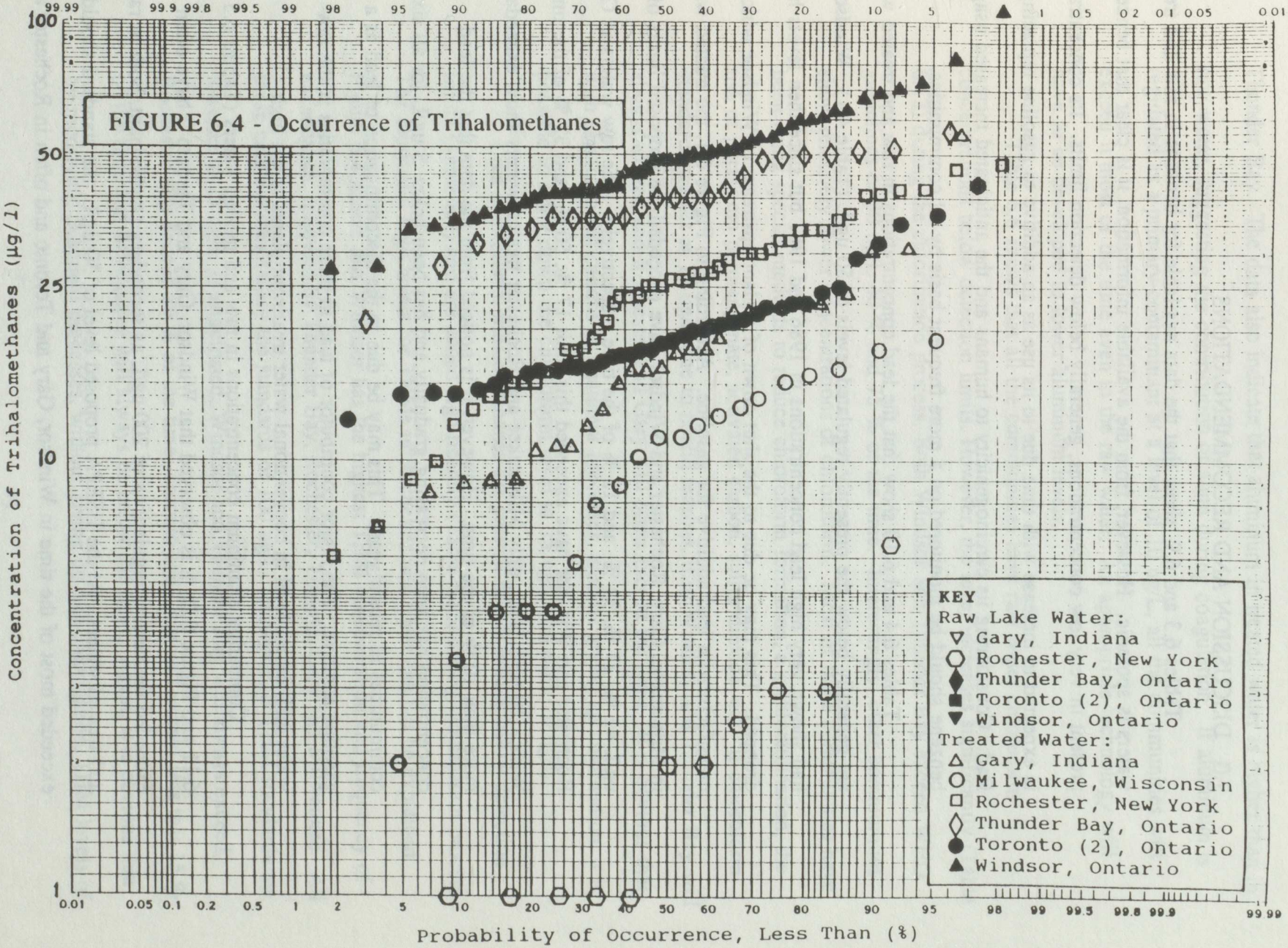


FIGURE 6.4 - Occurrence of Trihalomethanes

7.0 DISCUSSION AND RECOMMENDATIONS

Tables 6.3 and 6.9 show that the data available for benzene in raw and treated waters is sporadic. However, from the available information, it is clear that benzene is present in very low concentrations, generally below detection limits. Its concentration is expected to increase with time due to its use as an additive to gasoline replacing lead. Considering its carcinogenicity to humans and the anticipated increased usage, benzene should be monitored on a more frequent basis by all communities.

Tables 6.4 and 6.10 show that the lead concentrations in raw and treated waters are generally below the presently regulated levels of 50 ug/L (Table 4.1). Windsor had shown very high lead concentrations in 1986 and 1987 but since then levels have dropped. This may be due to the shut down of a plant upstream of Windsor which manufactured a lead additive for gasoline. According to Figure 6.1, the treated waters in Milwaukee, Gary, Rochester and Windsor have exceeded the proposed limits of 5 ug/L 43 %, 27 %, 33 % and 12 % of the time respectively. The raw waters in Gary, Rochester and Windsor have exceeded this limit 17 %, 50 % and 32 % of the time. With a 10 ug/L limit, only Milwaukee and Rochester treated waters show exceedance more than 10 % of the time. However, it is noticed from the data that the lead concentration has been decreasing gradually and has been below 5 ug/L for all six communities in recent years. This may be due to the discontinuation of lead as a gasoline additive. The major contributor of lead in these communities is the raw water and the removal in conventional water treatment plants is not high.

Comparing aluminum concentrations in raw and treated waters (Tables 6.5 and 6.11 and Figure 6.2), it is observed that Windsor, Gary and Toronto 2 have often exceeded the current regulations of 200 ug/L as secondary contaminant, both in raw and treated waters. At the USEPA proposed level of 50 ug/L, the standard should be exceeded most of the time in Windsor, Gary and Toronto and often in Rochester and

Thunder Bay. The data also indicate that aluminum in treated water is higher than in raw water, suggesting the contribution of alum during coagulation. If aluminum is regulated as a primary contaminant at a level of 10 ug/L, all the communities will exceed it most of the time even in the raw water. An appropriate technology will have to be developed to lower aluminum levels.

Table 6.6 shows that all the communities have raw water chloroform concentrations below detection limits. However, the level increases significantly (Table 6.12) during the chlorination process. Both Windsor and Thunder Bay exceed WHO guidelines of 30 ug/L 40 % and 75 % of the time. Interestingly, other communities show relatively lower concentrations of chloroform. Most of these communities have been using special methods to reduce chloroform formation, e.g chloramination, the use of potassium permanganate, activated carbon, sulfur dioxide, etc. If chloroform standards are set at 15 ug/L due to health reasons, then Windsor and Thunder Bay will always exceed and Rochester and Gary will often exceed the limit. It is obvious that with certain modifications in treatment processes, without giving up chlorination, it is possible to bring down the chloroform level to 15 ug/L and even 10 ug/L.

Like chloroform, trihalomethanes are present in raw waters below detection limits (Table 6.7) and are added significantly (Table 6.13) during chlorination process. The unusually high levels for THMs in Rochester raw water can not be explained. Figure 6.4 shows that Windsor has the highest THM concentration and frequency of exceedance, followed by Thunder Bay, Rochester, Toronto, Gary and Milwaukee. All these communities satisfy the standards of 100 ug/L. However, if THM standards are lowered to 25 ug/L as anticipated, Windsor and Thunder Bay will always exceed, Rochester will exceed 50 % of the time, Toronto and Gary will exceed less that 15 % of the time and Milwaukee will always be below the limit. Again, it is obvious that by modifying treatment processes, without giving up free chlorination, THM levels of

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